Context-Awareness in a Persistent Hospital Companion Agent

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Abstract. We describe the design and preliminary evaluation of a virtual agent that provides continual bedside companionship and a range of health, information, and entertainment functions to hospital patients during their stay. The agent system uses sensors to enable it to be aware of events in the hospital room and the status of the patient, in order to provide context-sensitive health counseling. Patients in the pilot study responded well to having the agent in their rooms for 1-3 days and engaged in 9.4 conversations per day with the agent on average, using all available functions.

Keywords: Relational agent, embodied conversational agent, medical informatics, health informatics, sleep promotion, sensors, accelerometer, RFID.

1 Introduction

Despite the bewildering array of technology in modern hospital rooms, little is provided for patients to directly interact with, aside from the television, telephone, and nurse intercom. Even in the academic research literature, few systems have been developed to provide information and comfort to patients while they are in their hospital beds. Although the purpose of hospitals is to heal acutely ill patients, they provide this service in a manner that largely treats patients as objects to be fixed rather than human beings to be supported and healed.

The hospital experience can be disempowering and disorienting. Patients face noise, sleep deprivation, frequent interruptions, an unfamiliar environment filled with many changing health professionals and ancillary staff, and medications that often have physical or psychoactive side-effects. At the same time, patients are often lonely and bored, left alone in their rooms until interventions are required.

In addition, many studies indicate that hospitalized patients are not engaged in their own hospital care at even the most rudimentary level. People frequently cannot identify the name or role of their providers [1]. After discharge, most patients cannot name their diagnoses or medications and few can name important potential side effects of their medications [2]. Expanding patients' role in their own care is an important goal: people who are more involved in their care have better outcomes, and helping patients establish their health agendas and promoting patients' questions about their care can improve outcomes (e.g., satisfaction, adherence, blood pressure control, and diabetes control) [3]. Currently, disagreements between patients and providers about basic aspects of the inpatient experience are common [4].

To help address these issues, we have developed a hospital companion agent that is designed to support a patient throughout a hospital stay. The "Hospital Buddy" is a virtual agent that is designed to chat with patients about their hospital experience—providing empathic feedback and emotional support—in addition to a range of topics that have medical and entertainment functions (Figure 1). A preliminary version of the Hospital Buddy that had limited, patient-initiated dialogue-only functionality was evaluated with three hospital patients in 2011 [5]. In this paper, we report on a greatly enhanced version of the system that integrates a suite of sensors to make the agent aware of events in the hospital environment and more aware of the status of the patient, to provide more context-sensitive and helpful counseling. We also report the results of a pilot acceptance study involving 8 patients.

Fig. 1. Patient Interacting with the Hospital Buddy

2 Related Work

Within the hospital environment, most HCI research has been clinician-centric, although there have been a few examples of patient-facing systems. Bers *et al.* developed a system that provided immersive multi-user collaborative support environments for hospitalized pediatric patients with renal and cardiac diseases [6], and other conditions. Bickmore *et al.*, developed a virtual nurse for hospital discharge education that was met with high rates of patient satisfaction [7]. Additionally, Wilcox *et al.* have shown that both patients and physicians are favorably inclined to having patient-facing health information displays located in the hospital room [8]. Vawdrey *et al.* piloted a tablet-based medical record portal with cardiology patients, and found that viewing their information helped patients feel more engaged in their care [9].

3 Design of the Hospital Buddy

Our interdisciplinary design team consisted of physicians, a medical student and computer science students and faculty. The team conducted a series of brainstorming meetings to identify possible functions for the Hospital Buddy. A series of storyboards were developed for promising functions and reviewed by the team.

The Hospital Buddy is deployed on a wheeled kiosk with a touch screen display on an articulated arm that can be positioned beside or in front of patients while they are in bed (Figure 1). The hardware setup also includes a UHF RFID antenna mounted on a separate arm (see Section 3.1), an omni-directional microphone, accelerometers for the patient to wear (see Section 3.2, Figure 3), and RFID tagged-badges for the hospital staff.

The user interface features a virtual agent whose nonverbal behavior is synchronized with a text-to-speech engine. User contributions to the conversation are made via a touch screen selection from a multiple-choice menu of utterance options, updated at each turn of the conversation. Several additional interface screens are used to provide "dashboard" displays of patient status, provider background information, and other information (Figure 2).

Fig. 2. Display Screens in Addition to Virtual Agent
"Dashboard" (left) and "Provider Biography" (right)

Agent dialogues are scripted, using a custom hierarchical transition network-based scripting language. In addition to network branching operations, script actions can include saving values to a persistent database or retrieving and testing values from the database, in order to support the ability to remember and refer back to information from earlier turns and prior conversations. Agent utterances can be tailored at runtime through the inclusion of phrases derived from information in the database or other sources, using template-based text generation. The virtual agent has a range of nonverbal behaviors that it can use, including: hand gestures, body posture shifts, gazing at and away from the user, raising and lowering eyebrows, head nods, different facial expressions, and variable proximity (wide to close-up camera shots). Co-verbal behavior is determined for each utterance using the BEAT text-to-embodied-speech system [10], with several enhancements to support health dialogues.

3.1 RFID-based Health Provider Identification

Up to 100 unique staff members may enter a patient's hospital room on a given day, and even those most closely involved with their care may be on irregular shift rotations, leaving patients confused about the identity and role of the hospital staff they interact with. Further, patients are not typically given an opportunity to provide feedback on the quality of these interactions during their hospital stay. To address these issues, we added a provider identification function to the system. Providers who approach a patient's bedside (and agree to wear an RFID tag) are detected and identified by the Hospital Buddy system using a long-range RFID reader, which then displays the provider's biography page, allowing the patient to view the provider's picture, name, role, and personal facts (Figure 2). At the end of the interaction (when the RFID reader detects that all providers have left the bedside), the agent prompts the patient to evaluate the provider and the interaction using standardized measures [11].

3.2 Accelerometer-based Sleep Detection for Hospital Patients

Hospital patients commonly experience fragmented sleep due to frequent interruptions, noise and other factors [12]. Fragmented sleep may be as detrimental to cognitive functioning as total sleep deprivation, and the effects of sleep deprivation are thought to be cumulative. Impairments to cognitive function can make it difficult for patients to be alert, engaged and receptive to information about their care. In addition, insufficient and fragmented sleep causes delirium (especially in older adult patients), limits patient learning and activation opportunities, and decreases patient satisfaction.

To address these issues, we extended the Hospital Buddy system to promote sleep management for patients by tracking their sleep and intervening with both patients and providers to ensure that patients get an appropriate amount of quality sleep. Sleep tracking is performed using real-time signal processing software, acquiring data from a small, wireless 3-axis accelerometer called a "Wocket" [13] (see Figure 3) worn on a patient's wrist. The Wocket attempts to send raw accelerometer data to the Hospital Buddy system via Bluetooth once per minute. If the patient is not in the Bluetooth range of the system, the system notes that the patient is absent, and the Wocket saves a 1-minute summary of wrist motion and sends that summary data during the next successful connection.

The Hospital Buddy computer processes the data as it is received and detects sleep and wake periods. The Hospital Buddy interface accordingly informs providers who approach a patient's bedside when the patient is sleeping and in need of sleep, presenting a text message and graph of recent sleep patterns to the care provider so that procedures that can be easily rescheduled can be deferred (Figure 2). When the

Fig. 3. Two Wockets, a charger and a Wocket worn in wrist band

patient does wake, the Hospital Buddy asks him or her about the quality of the completed sleep episode and records this information for hospital staff.

The sleep-detection software was validated vs. polysomnography (PSG), the gold standard for sleep detection [14], in a pilot study. For 10 hospital patients the PSG sensors (EEG, EOG and chin EMG sensors) were set on the head and two Wockets were worn, one on the wrist and the other on the ankle, for 20 hours each. The PSG data were manually labeled by a clinician in the hospital's Sleep Disorders Center in 30-second epochs according to American Academy of Sleep Medicine guidelines [15]. The sleep-detection software was trained with Wocket data and the PSG labels to build the accelerometer-based sleep detection model using an algorithm modified from Sazonov *et al*. [16]. The algorithm detected sleep/wake states with 82.7% accuracy for one Wocket on the wrist, and 74.5% accuracy for one Wocket on the ankle, where results were analyzed using 10-fold cross validation.

3.3 Acoustic Identification of Medical Device Alarms

Audible alarms on medical devices such as infusion pumps, and monitors such as pulse oximeters, are common in the hospital environment. The sheer number of alarms may result in alarm fatigue and decreased provider responsiveness, or even to alarms being disabled, silenced, or ignored [17]. Unexplained alarms can also cause patient anxiety, and the noise caused by frequent alarms can disrupt patient sleep.

To address these problems, we extended the Hospital Buddy with a microphone and signal processing software to detect and identify audible alarms in the hospital room (monitoring devices in many hospitals, including ours, do not provide digital alarm outputs). When an alarm is detected and identified, the Buddy proactively explains the alarm to the patient, so the patient understands what the alarms in the room are and their implications for care. Patients are also counseled on behaviors they can avoid that may trigger false alarms (e.g., certain kinds of motion, removing biometric monitor leads, etc.), reducing false alarm rates.

To identify the source of frequent alarms and to collect samples for training, we collected audio recordings from 11 patients totaling over 250 hours of hospital room sounds. Samples of interest were extracted and labeled by clinicians. This resulted in six types of frequent hospital alarms that we wanted the system to identify: IV standby, IV check, bed, dash monitor, blood pressure monitor and cardiac monitor alarms. Based on the type of the detected alarm, the Buddy initiates a corresponding dialogue, providing empathetic feedback, explaining the alarm and its potential causes, and suggesting actions to be made (e.g., calling the nurse). In addition, the system offers the patient options to immediately add the alarm issue onto an agenda of problems to be discussed with the medical team.

We developed signal-processing software to identify the six alarms from real-time audio. An audio buffer of length 20 seconds is used for processing the input signal. The frequency of each alarm was measured and used to design a high pass filter that is used to remove the noise from the input signal. The envelope of the signal is extracted by a full-wave rectifier and a low pass filter. The envelopes of the alarm signals contain pulse trains with specific patterns. The pulse width and the pulse period are used for detecting these patterns. Each alarm detector looks for pulses that have amplitudes higher than a specific threshold. The detectors match the pulse width and period with their related alarm pattern to identify the alarm. Results of alarm identification testing on recorded hospital sounds are presented in Table 1.

Table 1. Acoustic Medical Device Alarm Identification Accuracy

Alarm type	**Precision(%)**	**Recall(%)**	**F1(%)**
Dash monitor alarm	85.36	83.33	84.33
IV pump alarm	83.52	81.72	82.61
Cardiac monitor alarm	88.46	86.25	87.34
Bed alarm	89.61	87.34	88.46
Blood pressure alarm	35.97	92.59	51.81

3.4 Additional System Functions and Overall Operation

In addition to the dialogue initiated by the Buddy in response to sensed events, patients can also initiate the following functions themselves via dialogue.

Dialogue about hospital events. This dialogue enables patients to discuss an event that just occurred to them in the hospital, such as: just waking up; just finishing a meal; just finished watching TV; family or friends just visited; or just had a procedure or test done. In each case, the agent elicits how the patient felt about the event, and provides empathic feedback when warranted.

Agenda Minder. This function maintains a prioritized agenda of unresolved questions and issues about the patient's condition and treatment. The agenda is built by the patient, with prompting by the Buddy and input from providers. The Buddy ensures that these agenda items get addressed by prompting patients and providers to discuss them during consultations with providers. Questions can be picked from a list of frequently asked questions, or typed via a soft keyboard.

Symptom Tracker. This function enables patients to self-report different subjective health-related states, such as pain and stress, and record them for later time-series display for their own use or to share with their providers (Figure 2). Patients can report any of a validated list of nine symptoms commonly experienced by hospital patients, the Edmonton Symptom Assessment System [18]. In addition to allowing patients to initiate self-report whenever they want, the Buddy prompts patients twice daily at preset times to describe how they are feeling. The agent also uses these patient utterances as empathic opportunities to provide comfort when appropriate.
Social Chat. The Buddy can engage in chat by telling the patient a story, selected from a list of health-related stories, anecdotes, and jokes.

The overall Hospital Buddy System operates in the following modes.
AGENT. Patient is talking to the agent, with no providers in the room. This can either be initiated by the patient, or when an event is sensed (a medical device alarm is identified, the patient just woke up, or it is time for a self-report of symptoms).
DASHBOARD. One or more providers are in the room, and either the patient is not present or asleep. In this situation, the "dashboard" is displayed, summarizing information that the Buddy knows about the patient, and a prominently-display notice to not wake the patient, if sleeping (Figure 2). The agent never interacts with providers directly because, based on our prior experience, providers are not receptive to this form of interface in the hospital environment.
CONSULT. One or more providers are in the room, and the patient is present and awake. Provider time is limited, and we did not want the agent interfering with provider consultation with the patient, so the virtual agent is not used in this situation. When providers first enter the room, their biography pages are displayed for the patient, but a provider or the patient can also view the patients "dashboard," sleep data, alarm data, agenda, or self-report history, to support consultation.
POSTCONSULT. Following a consultation, and 5 minutes after all providers have left the room, the agent appears and prompts the patient to rate their providers and their interactions.

4 Pilot Evaluation Study

To evaluate the Hospital Buddy, we conducted a formative pilot test in which hospitalized patients used the system continuously for one to three days. The study was conducted on a general medicine floor at an urban hospital.

Following the administration of informed consent, patients were given a brief introduction to the system functionality. Providers who agreed to participate and wear RFID tags were also consented and given an overview of the system. The system was then left in the patient's room for one to three days. A research assistant visited the patients once per day to switch and recharge the Wockets. Upon the study completion, we asked the patients to complete questionnaires, followed by semi-structured interviews with both patients and their providers.

We recruited 8 patients: 50% female; aged 33-53 (M=47); 33% were African American, 33% were Hispanic or Latino; 33% had college degrees, 50% had high school education; 83% reported using computers regularly; 50% had inadequate health literacy according to the REALM test. Eleven providers (all female, 36% doctors and 64% nurses) were recruited from the same unti.

Results

System Use. All patients used the system for 1 to 3 days (mean 1.38 days). Patients had an average of 9.4 (SD=4.5) conversational interactions per day with the agent, 44% of which were initiated by the patients. The average duration of the conversations was 115 seconds (SD=107.2).

Working Alliance. Table 2 presents the patients' self-report ratings of their relationship with the Buddy [19]. The patients showed confidence in the Hospital Buddy's ability to help them and felt that the Buddy was genuinely concerned about their wellbeing.

Table 2. Patients' Working Alliance Inventory [19] Ratings of the Hospital Buddy

Rating Items (Scale Measures from 1-7) *1 – Strongly Disagree 7 – Strongly Agree*	**Mean (SD)**
I feel uncomfortable with the Buddy	2.4 (2.6)
The Buddy and I understand each other.	4.4 (2.1)
I believe the Buddy likes me.	5.4 (2.5)
I believe the Buddy is genuinely concerned about my welfare.	6 (1)
The Buddy and I respect each other.	6 (1)
I feel that the Buddy is not totally honest about her feelings toward me.	2.2 (1.6)
I am confident in the Buddy's ability to help me.	5.8 (2.2)
I feel that the Buddy appreciates me.	5 (2)
The Buddy and I trust one another.	3.8 (2.3)
My relationship with the Buddy is very important to me.	4.8 (1.9)
I have the feeling that if I say or do the wrong things, the Buddy will stop working with me.	2 (1.2)
I feel the Buddy cares about me even when I do things that she does not approve of.	5.4 (2.5)

Symptom Reporting. 75% (n=6) of patients used the symptom reporting function, demonstrating a strong engagement in this activity with an average of 1.9 (SD=1.2) reports per day from each patient. Providing dual channels for symptom reporting was shown to be effective, resulting in both patient-initiated selective symptom reports (62%) and scheduled, agent-initiated symptom reports (38%). During the interviews, patients reported positively on the ability to proactively track their symptoms. One patient indicated that the graph visualization of her symptom progress helped her to process the information more easily. One patient also envisioned the potential of this function to facilitate information sharing among their care team, who often work on different time schedules.

Agenda Management. 50% (n=4) of patients used the agenda function, recording questions about specific medical terms (e.g. *"What is MRI?")*, events (e.g. lab tests or alarms) and general concerns about their conditions (e.g. *"How can I prevent this?")*. One patient checked off his agenda item as an indication that the item had been resolved. Both patients and providers reported highly positive feedback on the concept of agenda tracking, noting that it allowed the patients to avoid the common problem of forgetting questions without relying on papers or external help from family members. Two patients specifically selected this function as their favorite part of the system and one provider described the idea as *"absolutely fantastic."*

Alarm Detection. An average of 15.3 (SD=17.8) alarms were detected daily for each patient, triggering an average of 2.4 (SD=3.7) agent-initiated discussions about alarms per day. In addition to agent-initiated dialogues, two patients proactively initiated their alarm dialogue with the agent. During these alarm conversations, there was only one instance that the patient indicated the detected alarm as a false alarm. While one patient noted that Hospital Buddy could help *"cut down on alarm time ringing,"* the high frequency of the agent-initiated alarm dialogues and the problem of occasionally detecting other patients' alarms sometimes causes confusion and frustration.

Provider Identification. Both patients and providers reported generally positive feedback on the ability to detect provider presence and display their biography, indicating that it acted as a *"great memory aid"* of their medical team. More specifically, one patient noted that she was *"always at the hospital and already know a lot of the people; however, they don't always write their name on the white board in the room."* None of the participants provided any provider ratings.

Sleep Monitoring. Due to technical issues, we were only able to collect sleep records from three patients, with the duration of detected sleep bouts ranging from 2 to 972 minutes. Only one of the patients provided a sleep quality rating. One patient noted that wearing the Wocket *"was comfortable,"* and that it could provide helpful information to both the patient and the hospital staff. Whether such information could change the behavior of both patients and providers, however, needs further study.

Companionship and Entertainment. Patients appreciated the ability of the Hospital Buddy to provide companionship during their hospital stay: *"She is always there…I know that there is somebody to respond to you right away…somebody next to me, someone to chat with."* Most (75%, n=6) patients used the storytelling function, with each of them listening to an average of 2.8 (SD=1.5) stories during their stay. Patients reported enjoying the stories, which could help calm them down when they were *"feeling bored and depressed with nothing going on,"* as *"it was something to do to keep your mind occupied."*

5 Conclusion

Patients were generally happy with the Hospital Buddy, and used all system functions. As in our pilot study, many patients felt the Buddy provided them with companionship in what otherwise can be an impersonal and bewildering environment. We experienced many technical difficulties with the various sensor systems, leading to a less than enthusiastic response from providers, who expect a high degree of reliability from technology. Future work includes improvements to the sensor systems and a properly powered randomized trial to evaluate the ability of the Hospital Buddy to increase inpatient satisfaction, sleep quality, symptom control, anxiety, loneliness, and depression.

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